An Interactive Web Accessible Gamma-Spectrum Generator

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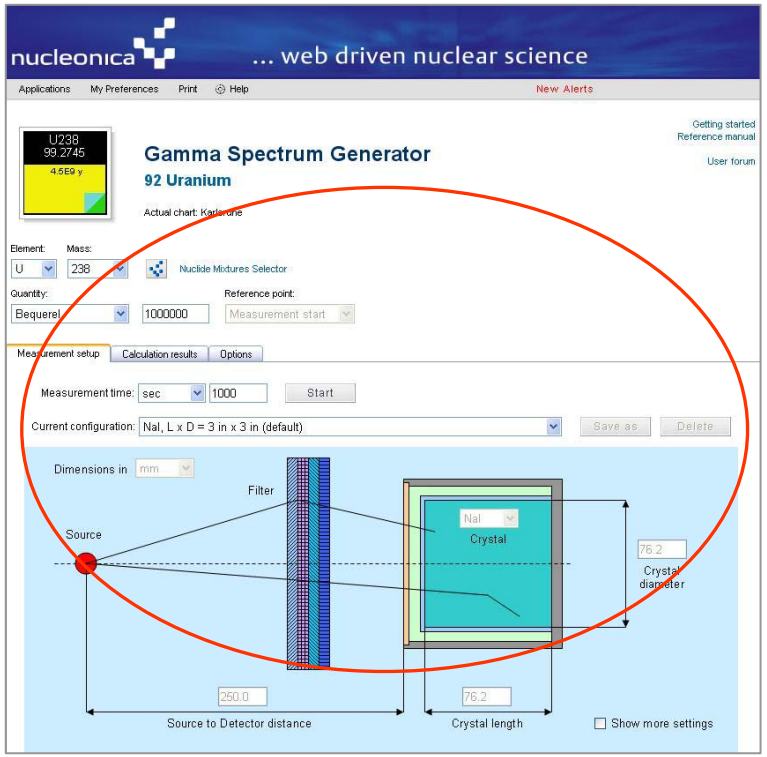
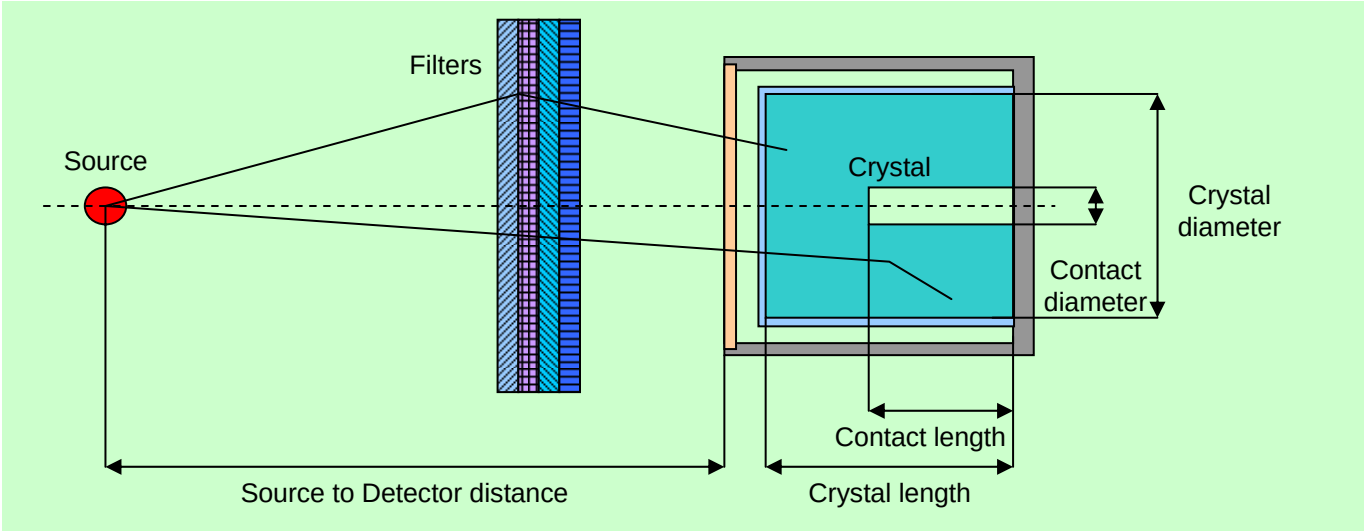


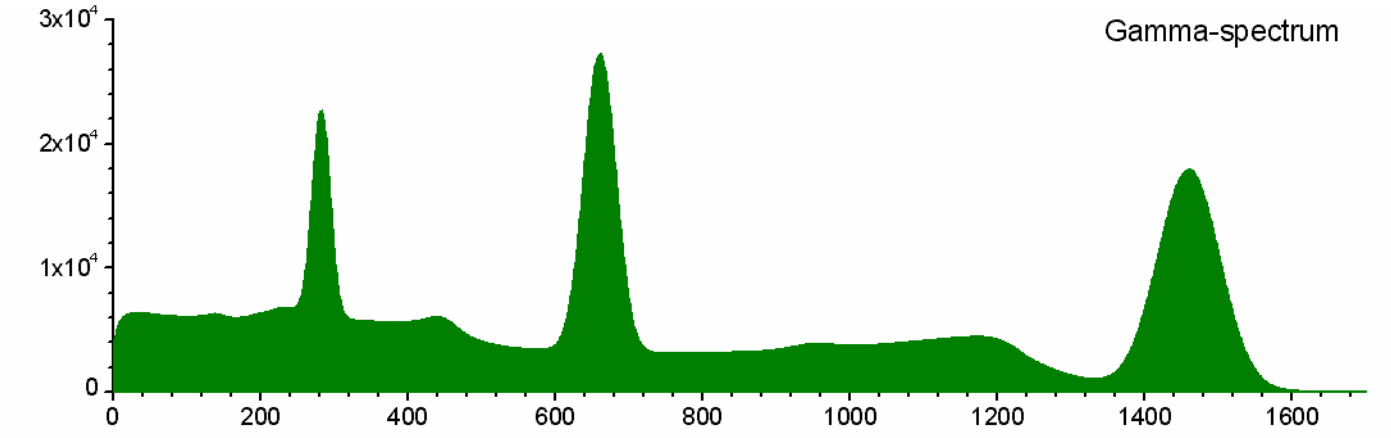
Outline

- Simulation approach
- Features implemented
- Some examples
- Future work
- Exercises

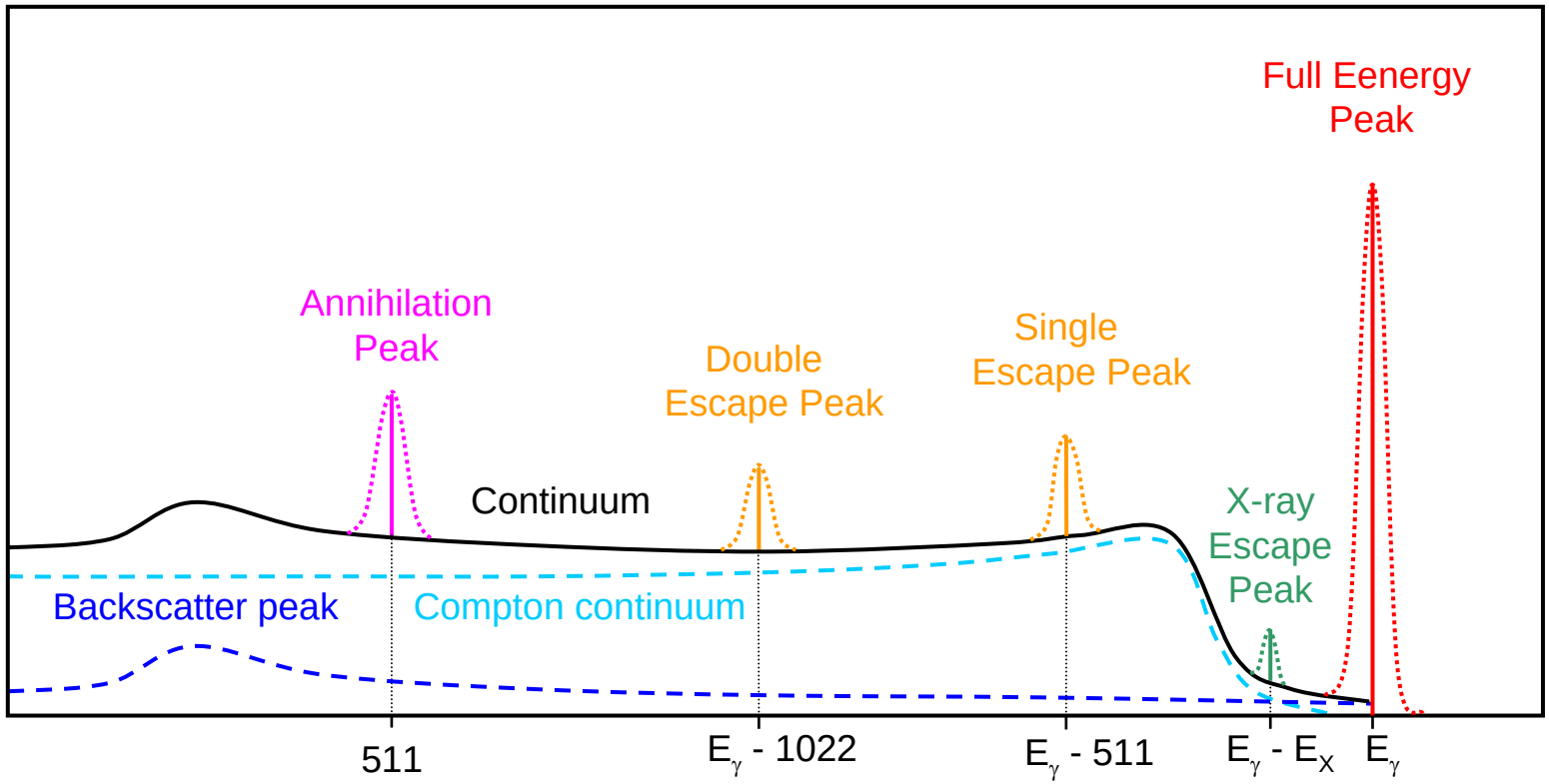
Measurement setup model implemented:



Spectrum modeling procedure:



Detector response profile model:



Detector Reference Response Profile DATABASE:

Method:

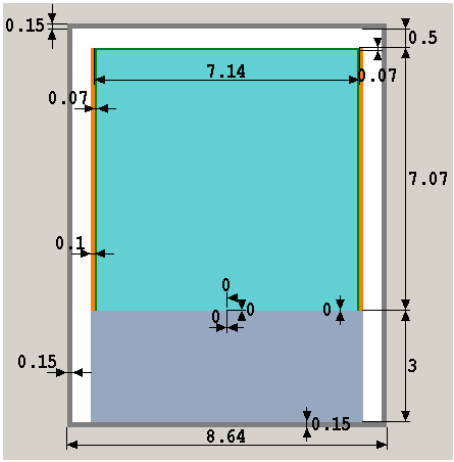
- Monte Carlo simulation using specially developed and validated program – DRGen (*Detector Response Generator*)

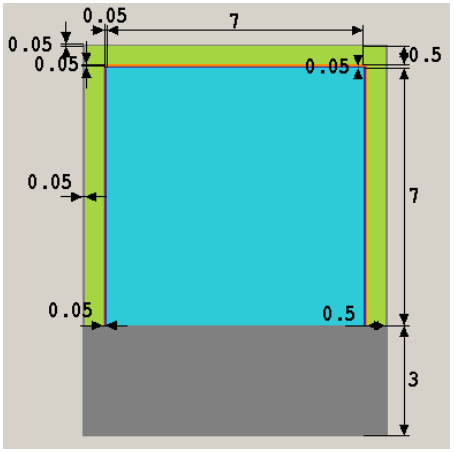
Content:

- Peak-to-Total efficiency ratios for FEP, SEP, DEP, XEP, and 511 keV annihilation peak
- Continuum-to-Total efficiency ratios for Compton continuum and Backscatter „peak“ distribution
- Parameterized shapes of Compton continuum and Backscatter „peak“ distribution

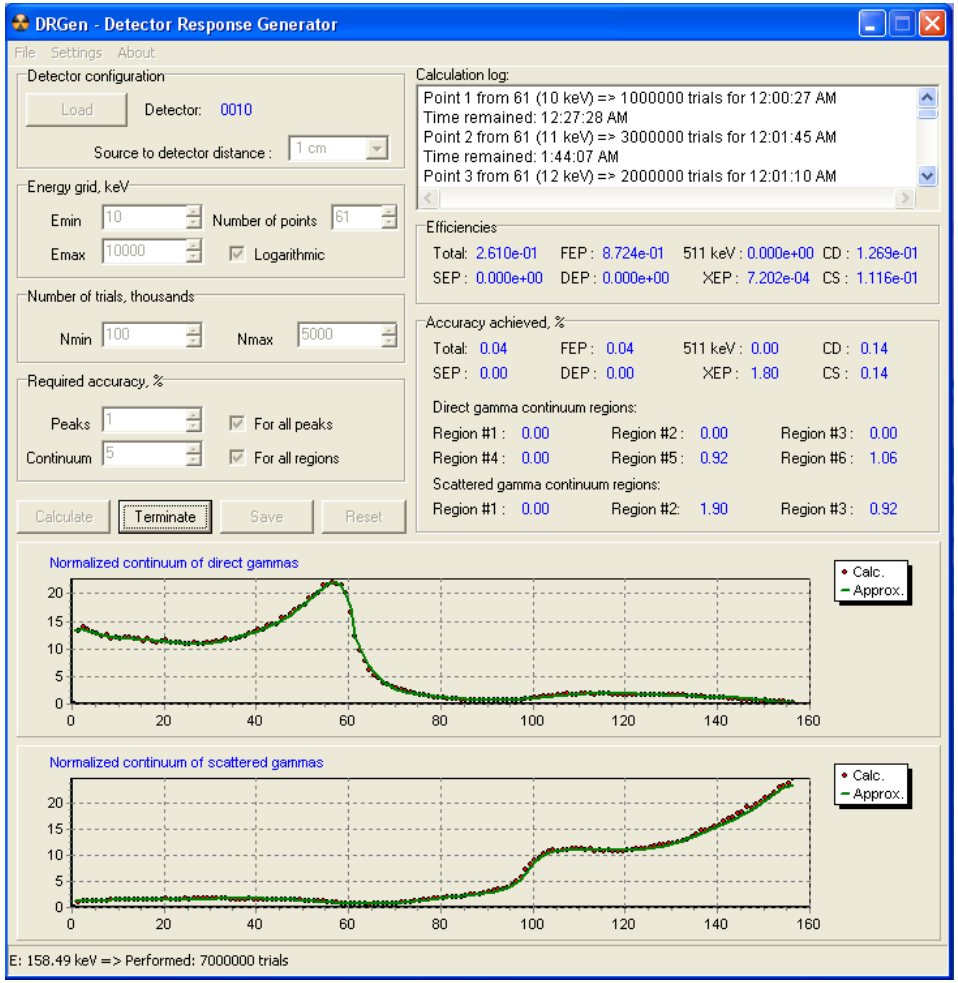
Scope:

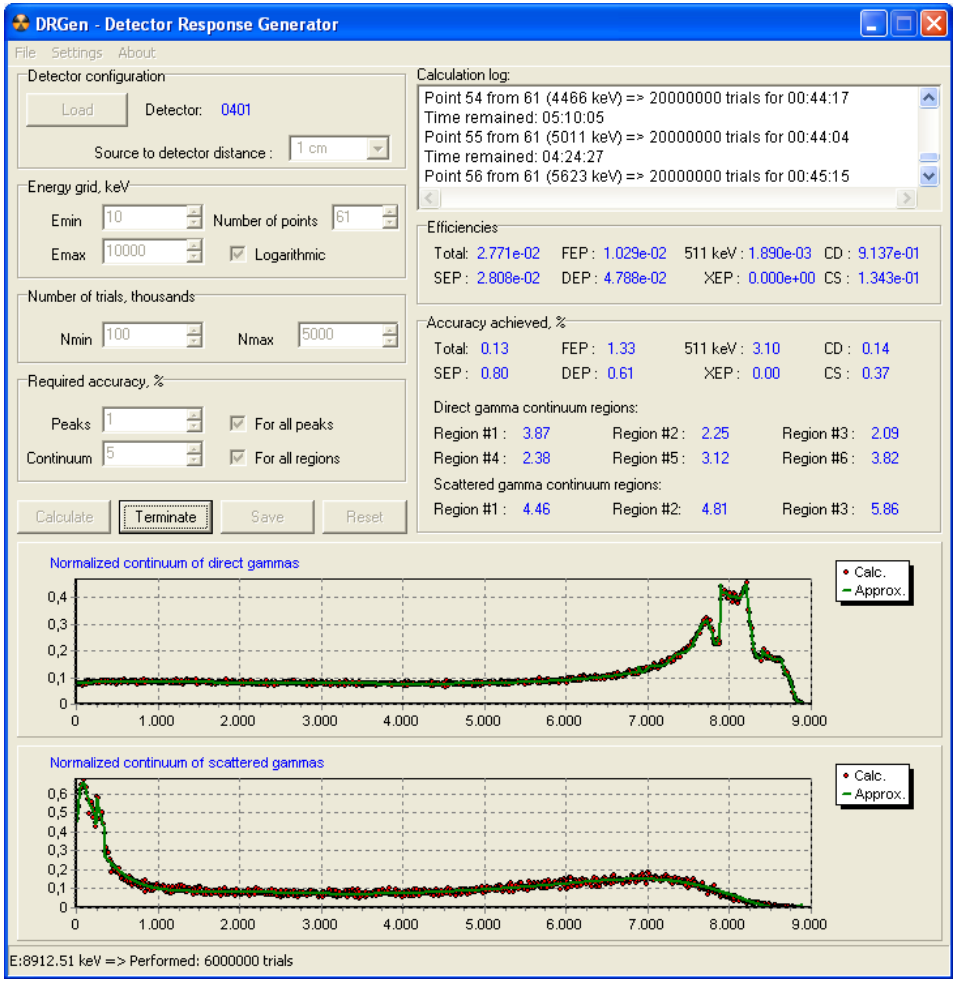
- Detectors: NaI and High Pure Ge (HPGe)
- Crystal length and diameter grid: 20 mm – 120 mm with 10 mm step
- Photon energy grid: 61 points, 10 keV – 10 MeV
- Source-to-detector distance grid: 0 mm, 10 mm, 50 mm, 250 mm
- Total number of profiles generated: 2 x 121 x 61 x 4 = 59048





DRGen (Detector Response Generator): creating the Detector Reference Response Profile Database

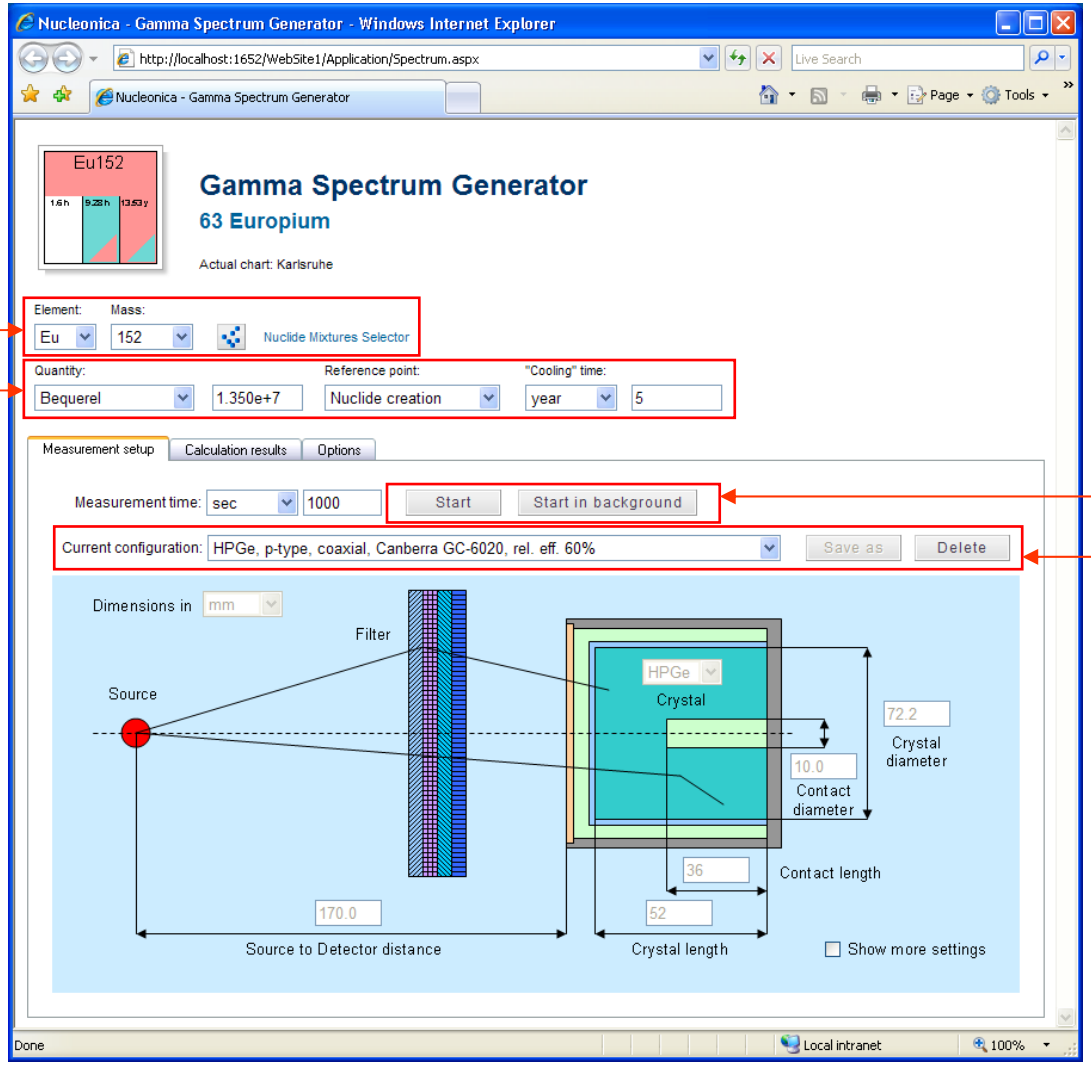




Features implemented: Measurement setup

An arbitrary individual nuclide or a pre-defined mixture of nuclides can be selected as a radiation source

The quantity (activity, mass or number of atoms) of a nuclide or a mixture can be specified either at the moment of its production or at the spectrum measurement starting point of time. In the former case controls for specifying duration of a source cooling time interval become available.



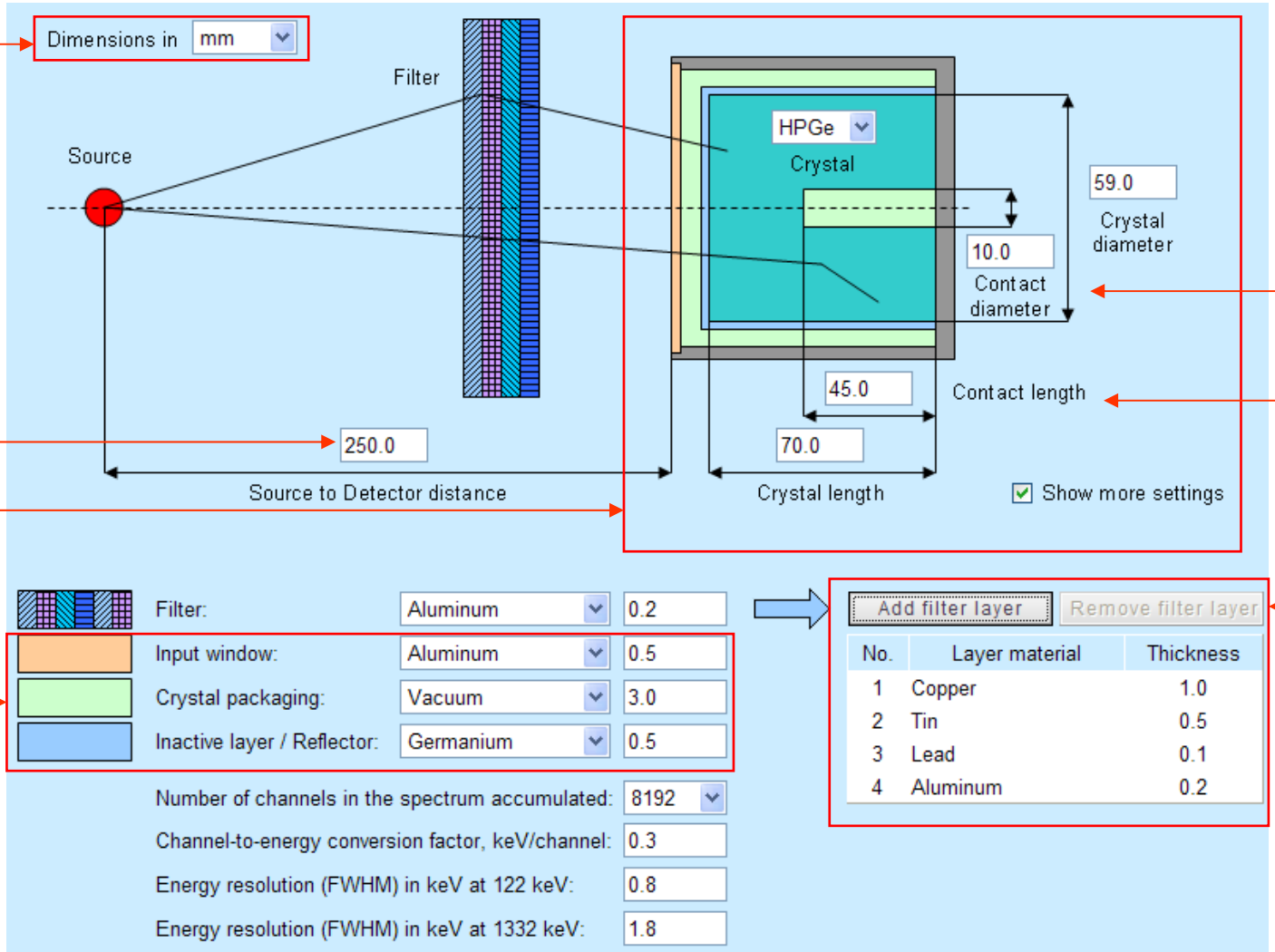
Calculations can be started on-line or in a background mode

A suitable γ-spectrometer can be chosen from 6 pre-defined configurations, which include 2 coaxial HPGe (50% and 150%) detectors, low-energy (LEGe) and broad-energy (BEGe) HPGe detectors, and 2 NaI detectors (∅3″×3″ and ∅2″×1″). In addition, user's specific configurations can be managed.

Features implemented: Measurement setup

Dimensions can be entered in “mm”, “cm” or “inch” units

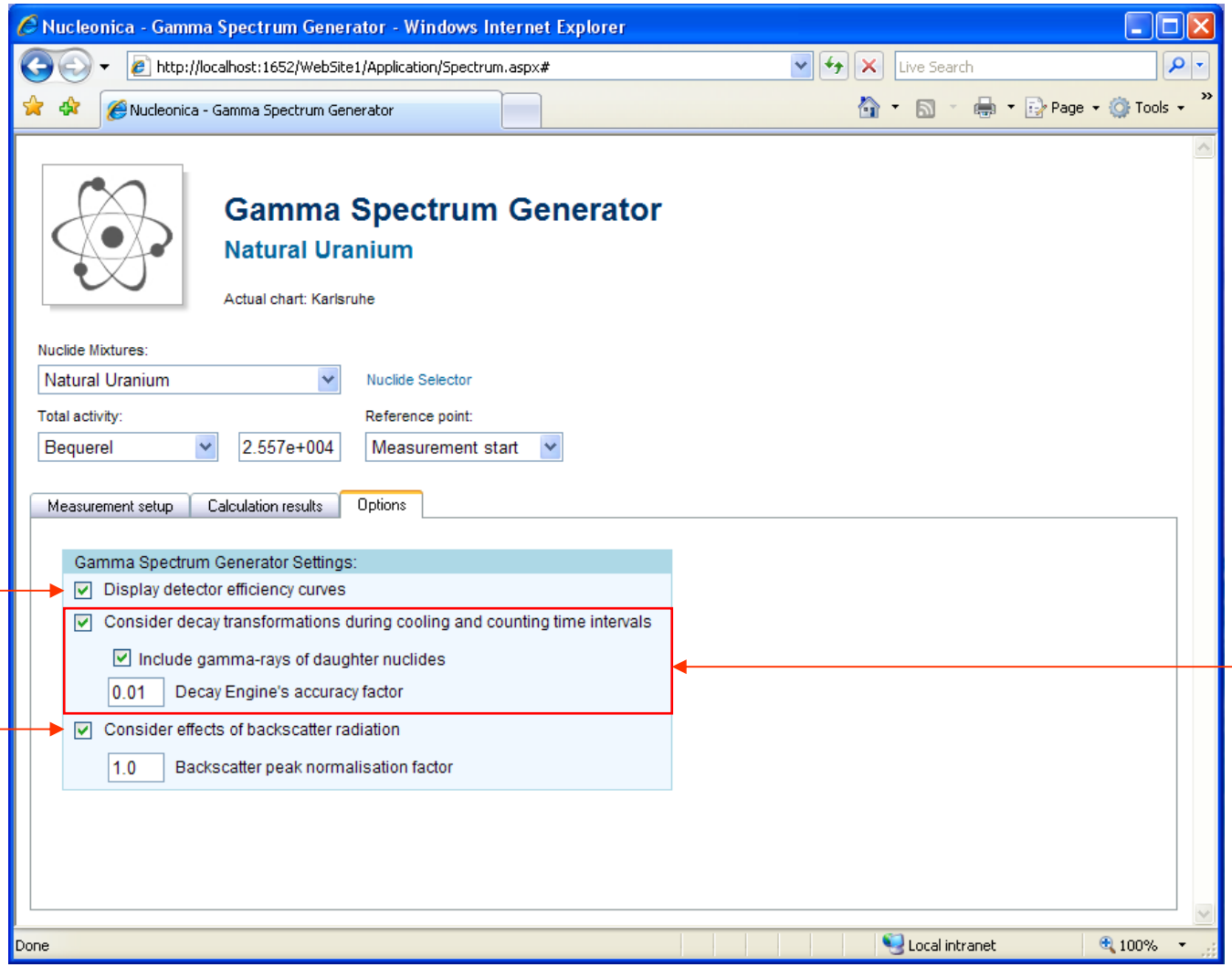
The configurable parameters include the source-to-detector distance, as well as dimensions and materials of the detector construction elements.



The dimensions of a cylindrical contact at the rear side of the crystal (a construction feature of conventional coaxial HPGe detectors) can be specified

Up to 6 additional absorbing filters made of Al, Cu, Fe, Pb, Sn, or polyethylene can be placed between source and detector

Features implemented: Options



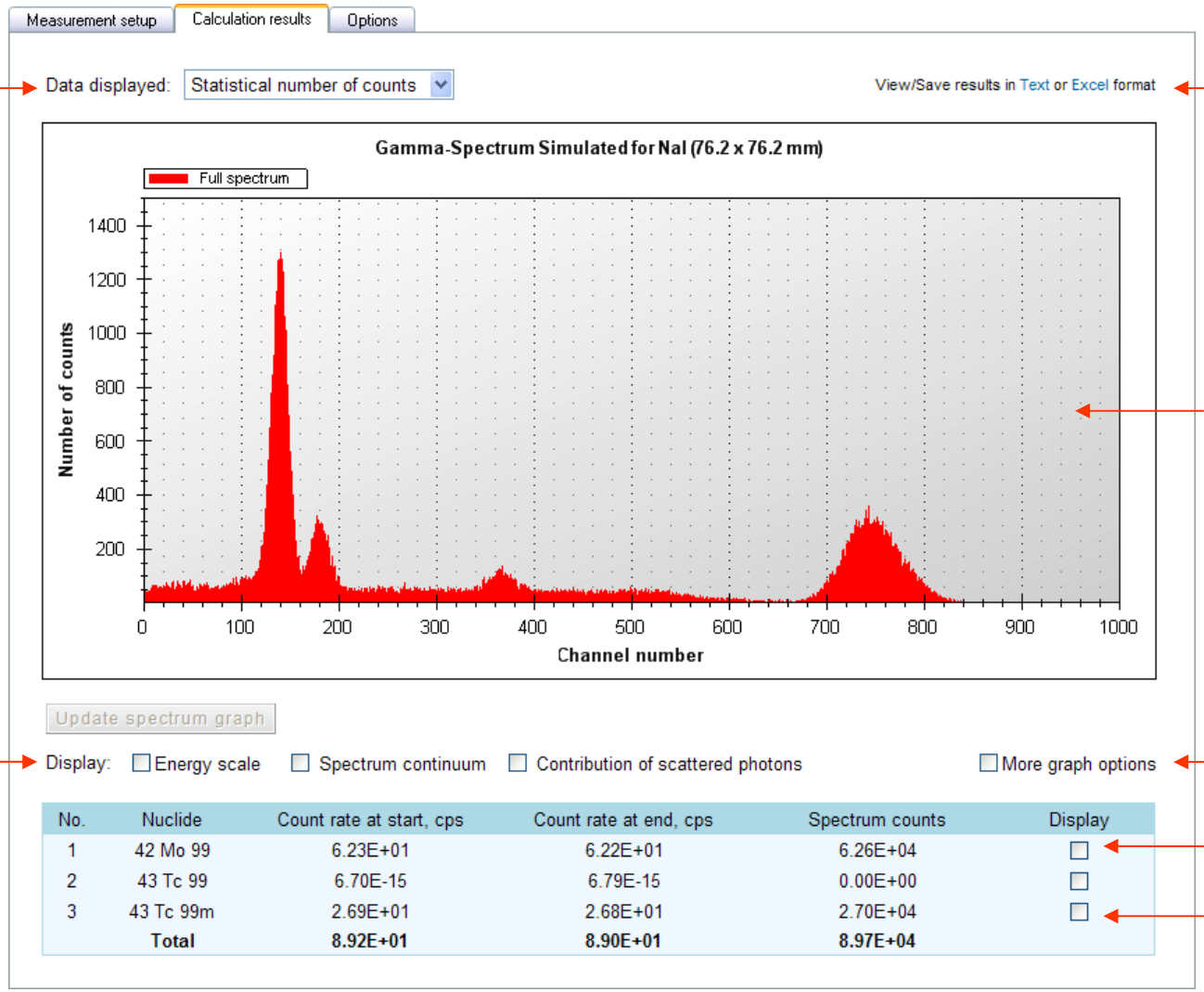
Efficiency Graph can be activated in the Calculation Results output

The backscatter peak simulation can be switched on/off, and its contribution to the spectrum can be adjusted

Decay calculations can be enabled that will allow contributions from decay products, being accumulated during source cooling and spectrum measurement time intervals

Features implemented: Calculation results

Statistical number of counts
Count rate at start
Count rate at end
Theoretical number of counts
Statistical number of counts



No.	Nuclide	Count rate at start, cps	Count rate at end, cps	Spectrum counts	Display
1	42 Mo 99	6.23E+01	6.22E+01	6.26E+04	☐
2	43 Tc 99	6.70E-15	6.79E-15	0.00E+00	☐
3	43 Tc 99m	2.69E+01	2.68E+01	2.70E+04	☐
	Total	**8.92E+01**	**8.90E+01**	**8.97E+04**	

Switch between channel number and energy scale; show peak, continuum and backscatter peak contributions to the full spectrum

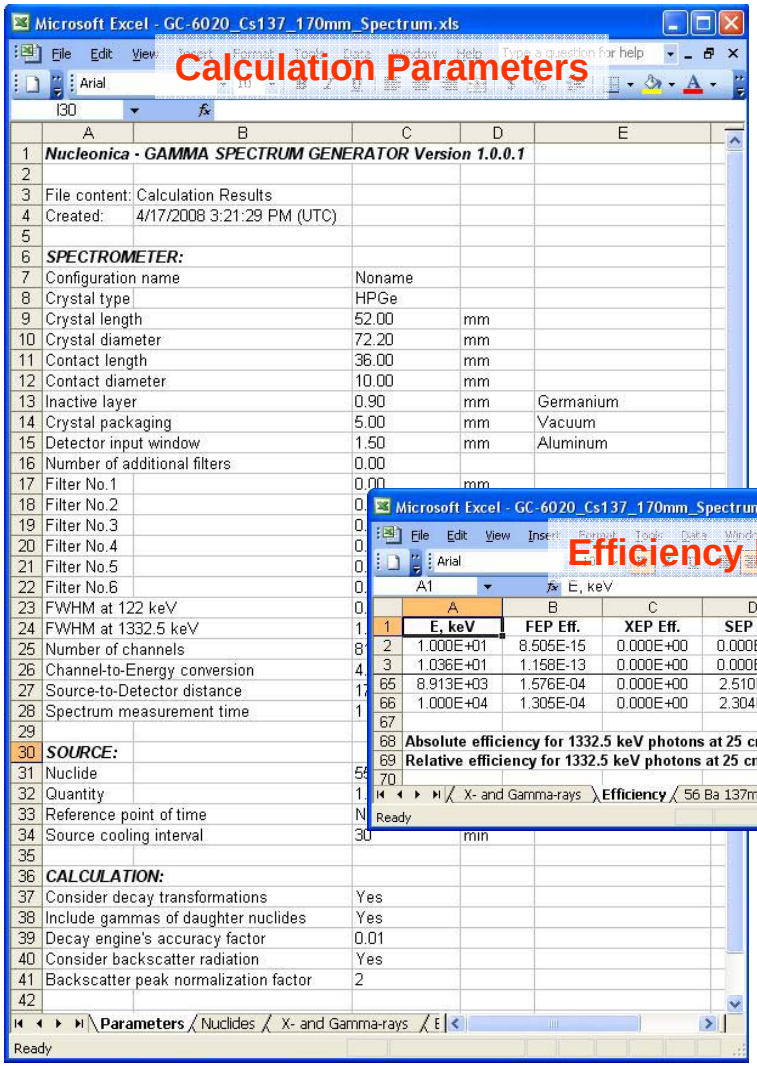
Complete set of spectral information can be downloaded as a text or Excel spreadsheet file

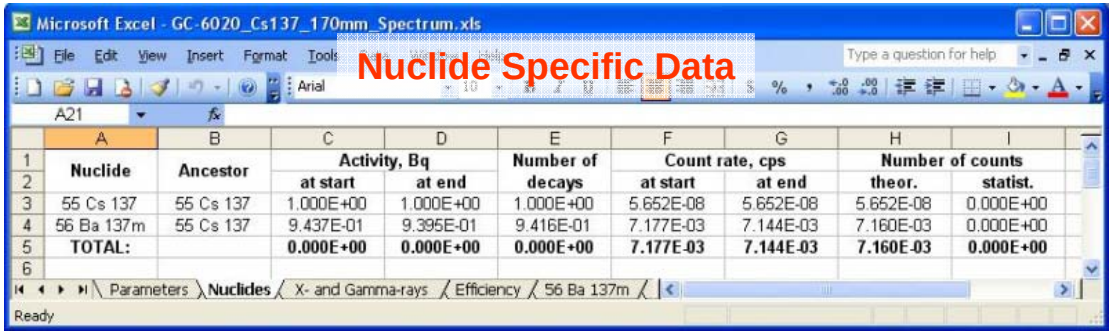
Right click within the graph area enables a context menu, from which one can print or download the spectrum graph

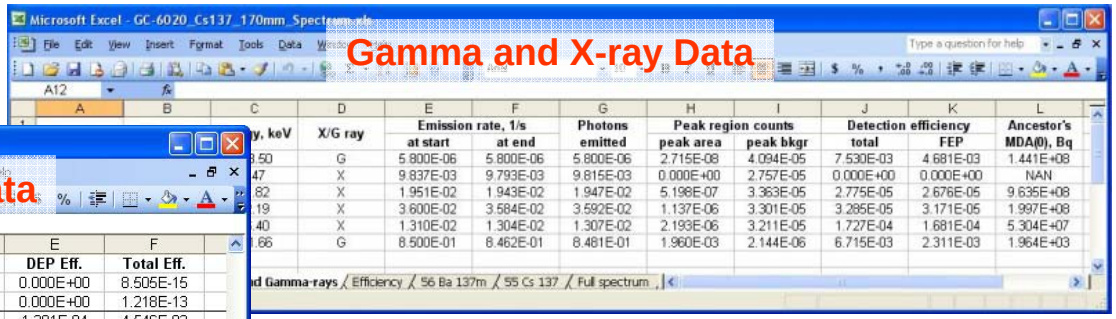
Additional options allow to customize appearance of the graph to meet one's needs and requirements

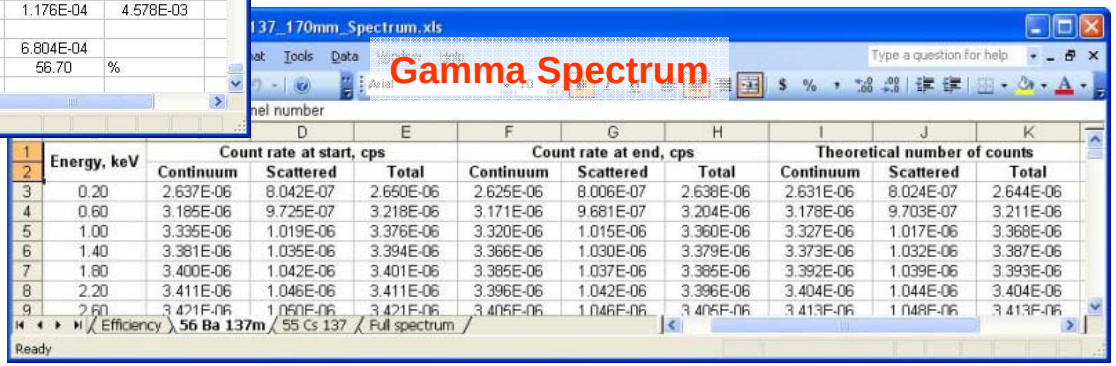
Display nuclide specific contributions to the full spectrum

Calculation results : Detailed Spectral Data in Excel Spreadsheet









Calculation results : Detection Efficiency

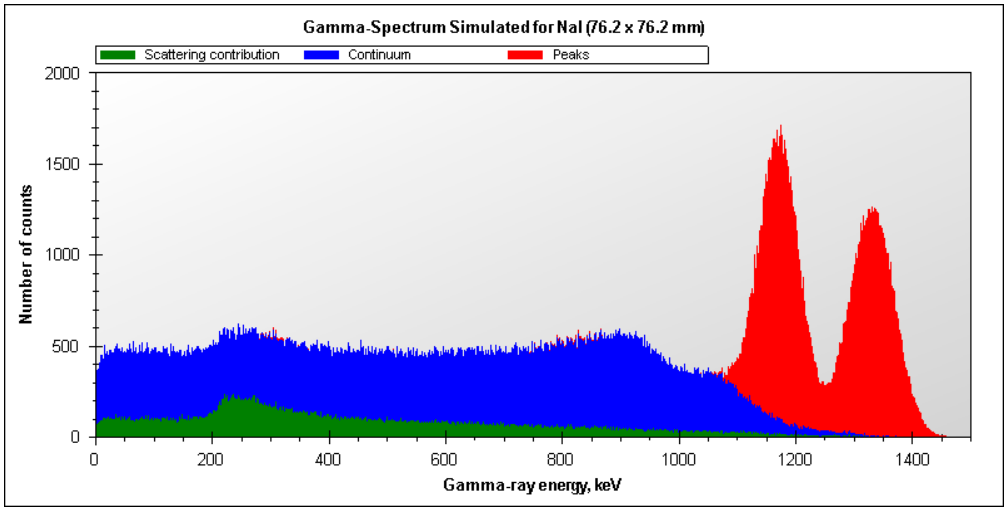
Right click within the graph area enables a context menu, from which one can print or download the efficiency graph

Select efficiency data to be displayed on the graph

Additional options allow to tailor the efficiency graph to one's needs and requirements

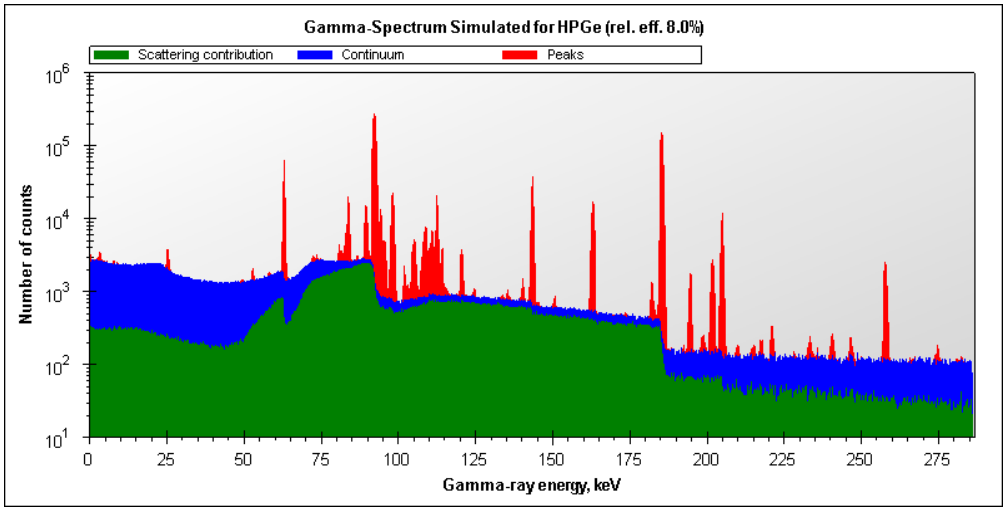
Examples:

100 kBq ^{60}Co



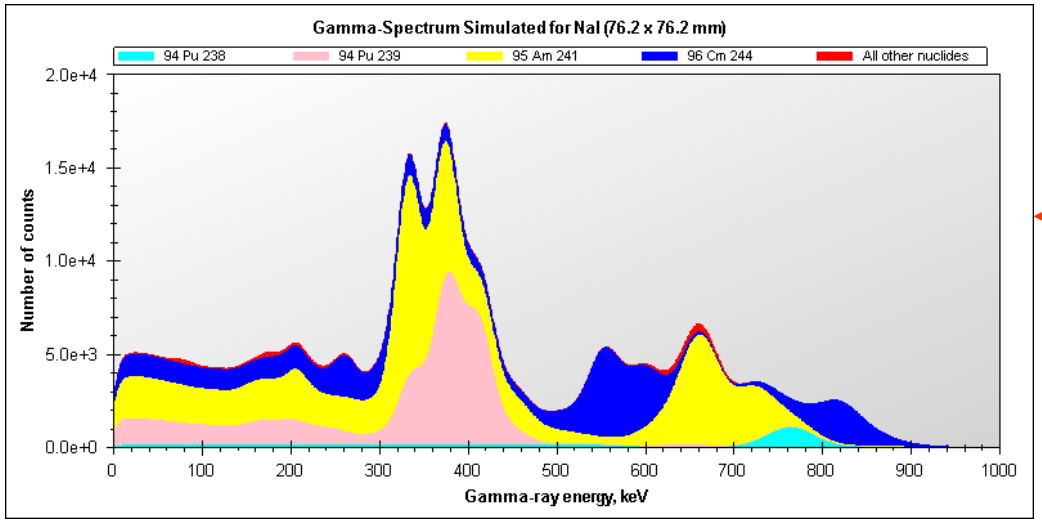
Detector - NaI (∅3″×3″)
Source-to-detector distance - 25 cm
Measurement time - 1000 s

1 g Nat U (2 years after separation)



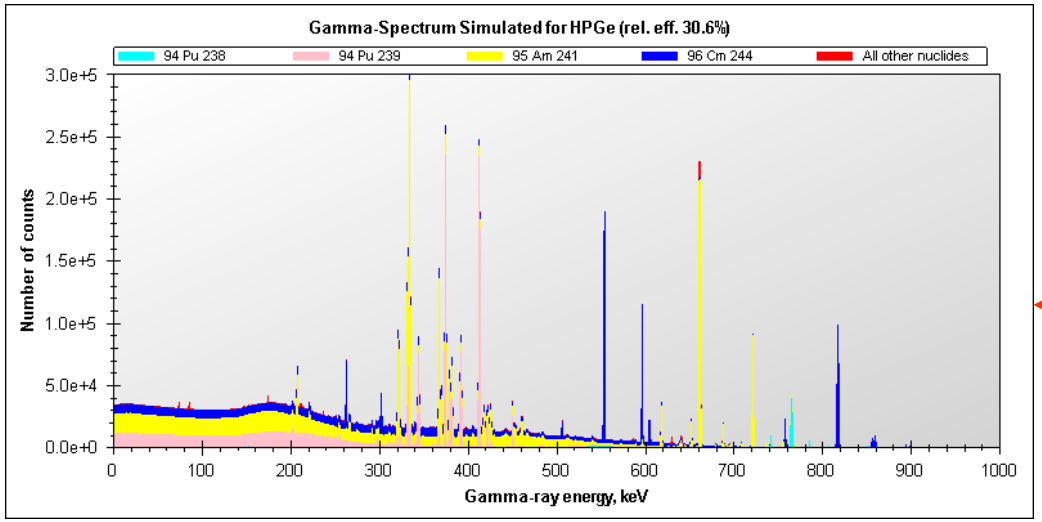
Detector – LEGe (20 mm × 2800 mm^2)
Source-to-detector distance – 25 mm
Filter – 0.5 mm Sn
Measurement time - 10^5 s

Examples:



Detector – NaI (∅3″×3″)
Source-to-detector distance – 25 cm
Filter – 5 mm Pb
Measurement time - 1000 s

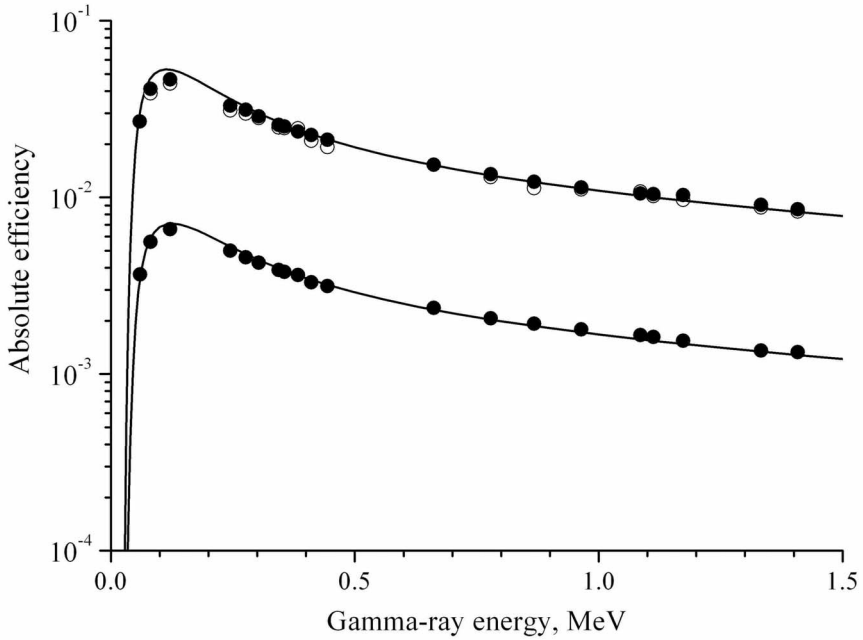
Actinides extracted from 1 kg 6-year-aged PWR spent fuel. Activity - 5.25 TBq



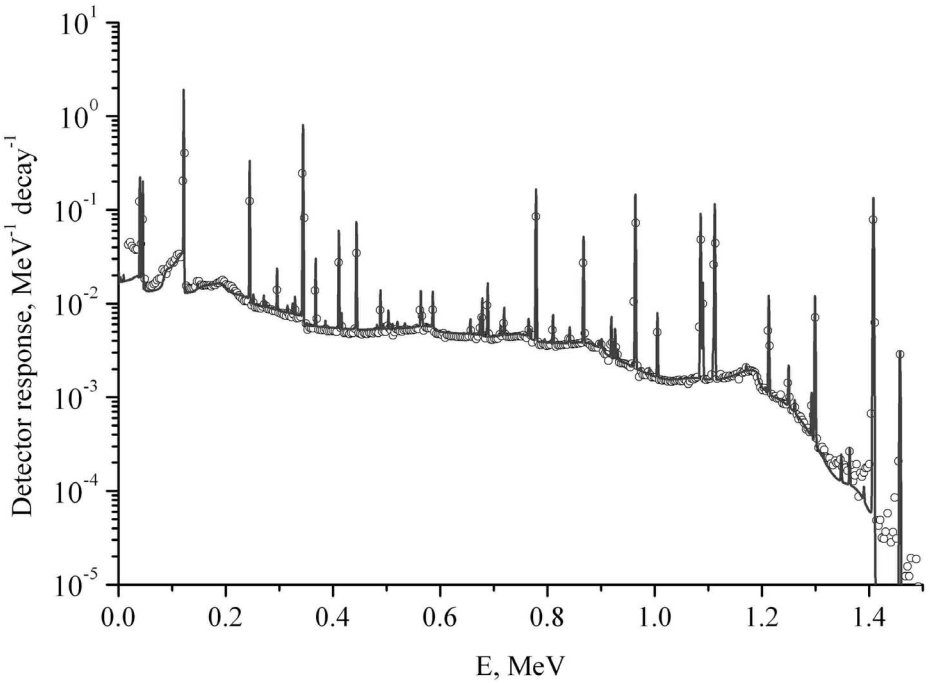
Detector – BEGe (30% rel. eff.)
Source-to-detector distance – 25 cm
Filter – 5 mm Pb
Measurement time - 1000 s

Example:

Results of the experimental validation with 60% HPGe coaxial detector



Full Energy Peak efficiency as a function of the photon energy: circles – experimental values, curve – calculated. Two sets of data refer to the source location at 5 cm and 17 cm distances from the detector end cap.



Calculated (curve) and experimental (circles) detector responses for ^{152}Eu source at 17 cm distance from the detector end cap.

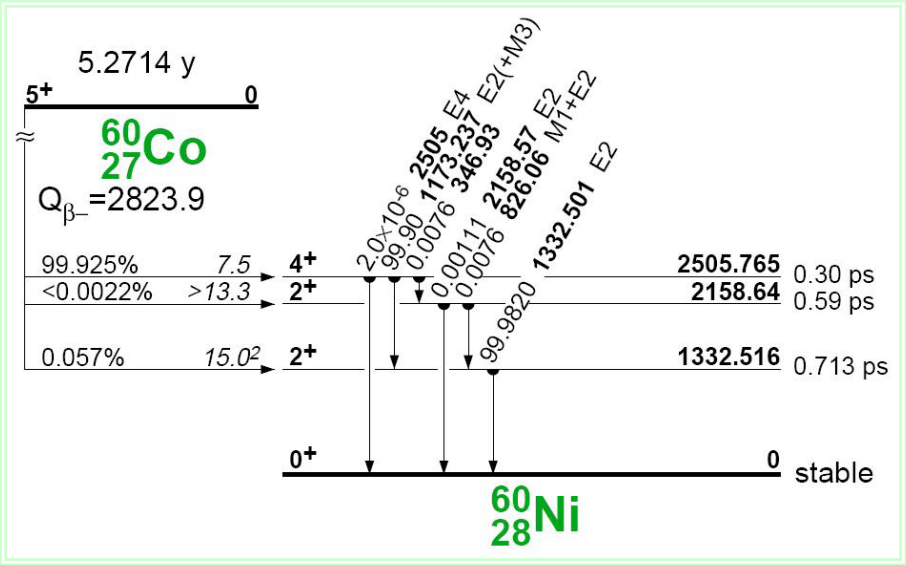
Future work:

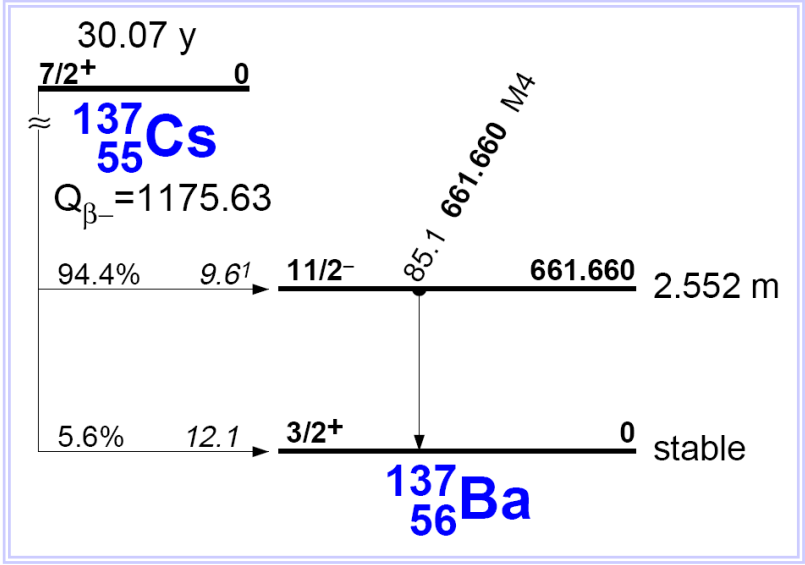
- Include simulation of the spectrum distortion effects (e.g. due to coincidence summing and energy resolution deterioration), which may appear in measurements involving elevated count rates and small source-to-detector distances.
- Extend the detector response profile database to include $LaBr_3$ scintillators that, because of their much superior energy resolution, start to replace traditional NaI crystals in many applications.
- Include self-attenuation effects (by combining GSG and EMC modules), which would allow more realistic simulation of gamma-spectra from voluminous sources.
- Include background gamma spectrum from naturally occurring radionuclides, which will make the spectrum shape and MDA evaluations more realistic.

Thanks for your attention !

Exercises:

1. **The measurement setup is similar to the default configuration "NaI, L × D = 1 in × 2 in (default)". You are going to calibrate it using the 1 MBq ^{60}Co and 1 MBq ^{137}Cs reference gamma sources. Approximately, how many statistical counts can you expect within 100 s in the corresponding gamma-spectra? Make the evaluations with and without backscattered photon contribution.**





Exercises:

2. **You have to measure the 10 MBq ^{152}Eu source with NaI (3"×3") scintillation detector in the measurement setup similar to the default configuration "NaI, L × D = 3 in × 3 in (default)". In your disposal there are three lead filters – 1 mm, 3 mm and 5 mm thick. Find the right combinations of the filters, which would make the measurement possible, assuming that your electronics can cope only with input count rates below 20 kcps (kilo counts per second). Check if the same electronics and filters will allow you to perform the measurement in the configuration "HPGe, coaxial, p-type, rel. eff. 150% (default)".**

3. **What is the relative efficiency of the HPGe detector with crystal length – 30 mm, crystal diameter – 50 mm, rear contact length – 20 mm, rear contact diameter – 10 mm, inactive Ge – 1.5 mm, cap thickness – 1 mm Al, and crystal to cap distance – 5 mm? What crystal length doubles the detector relative efficiency?**

Exercises:

4. The 1 g natural uranium sample (^{234}U – 0.000055 g, ^{235}U – 0.0072 g, ^{234}U – 0.992745 g) was measured twice on the same NaI (3"×3") scintillation spectrometer (configuration "NaI, L × D = 3 in × 3 in (default)"). The first and the second measurements were performed for 100000 s respectively 10 days and 1 year after the uranium separation. What are the relative contributions of ^{235}U and ^{238}U to the gamma-spectrum measured in both cases? When modeling the spectra, use 1 mm Pb filter to imitate the self-attenuation properties of the sample.

5. Based on the gamma-spectrometric examination of a source, the presence of ^{60}Co with activity 100 kBq was revealed. Which of the default GSG measurement configurations are suitable for detecting an additional presence of 50 Bq of ^{241}Am in the same source by performing a 1000 s long measurement?